

Advanced Environmental Economics: Modelling and Empirical Approaches

Lecture 4: Hands-on Modelling

Felix Schaumann | 25.04.2024

2010

2025

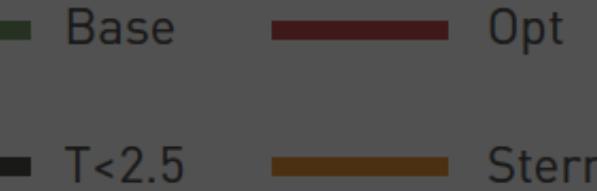
2040

2055

2070

2085

2100



Recap

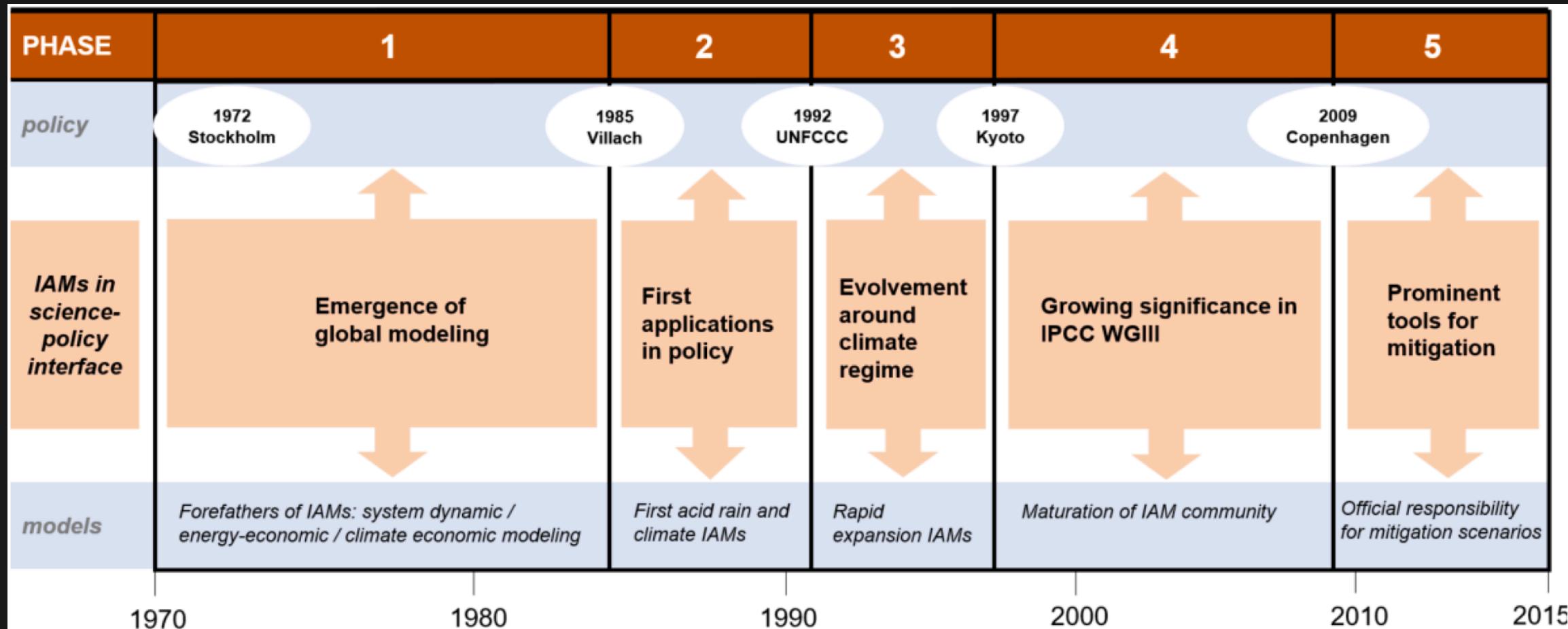
What have we done so far?

1. Introduction
 2. Modelling and the economics of climate change
 3. Empirical Approaches
- Any questions before we move on?

This lecture

1. IAMs: a brief history
2. How to code IAMs?
3. How to run an IAM in Mimi

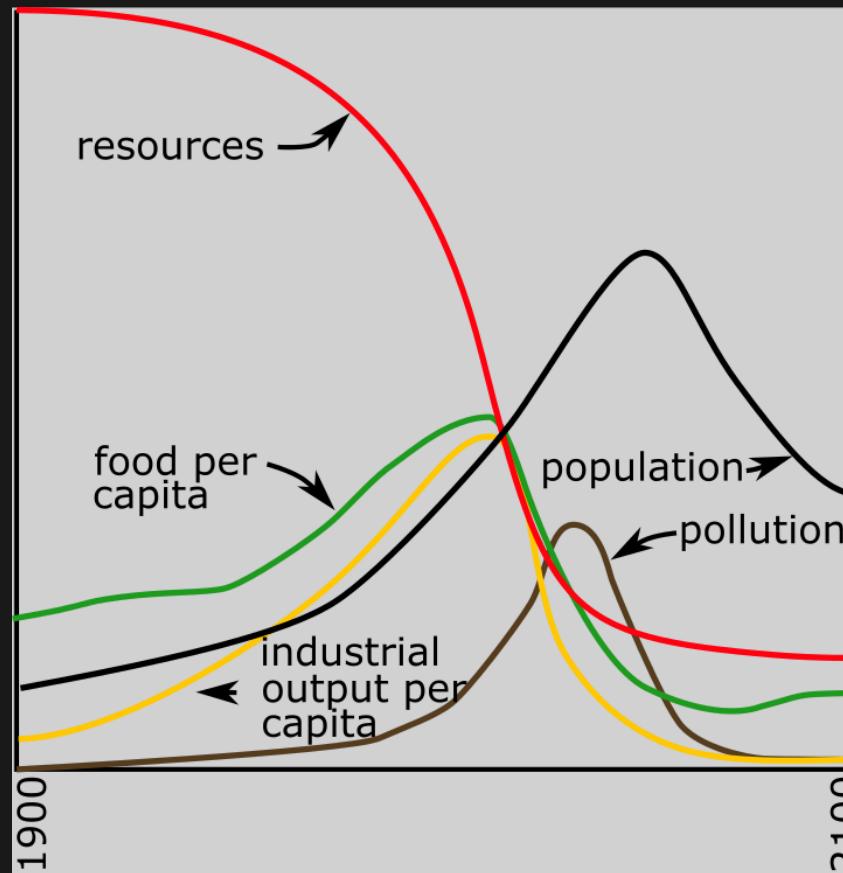
1. IAMs: a brief history



van Beek et al. (2020)

1972: Arguably the first IAM

- *The Limits to Growth* (Meadows et al., 1972)
- First report to the Club of Rome
- World3 simulation model
- birth of *system dynamics*
- similar: Bariloche model (Herrera et al., 1976)



- critiqued by Nordhaus (1973)
- controversial within economics
- influential for environmental movement

IPCC definition of **integrated assessment**:

“A method of analysis that combines results and models [...] in a consistent framework to evaluate the status and the consequences of environmental change and the policy responses to it.” (Allwood et al., 2014, p. 1264)

Nordhaus: integrating climate change into economics

TABLE 1. CONTROL STRATEGIES

1. REDUCE EMISSIONS:
 - A. REDUCE DEMAND*
 - B. SUBSTITUTION IN SUPPLY*

2. NEGATE DAMAGES
 - A. MIX INTO OCEANS
 - B. OTHER OFFSETTING EFFECTS (PARTICULATES, PAINT, BAND-AIDS)

3. CLEAN UP EX-POST
 - A. REMOVE FROM AIR
 - B. GROW TREES

4. NATURES WAY AND PRAY

 DO NOTHING (RULED OUT)

*CONSIDERED IN MODEL

Nordhaus (1975, IIASA)

Fig. 2. Greenhouse-gas concentrations. Concentrations of GHGs (including CO₂ and CFCs, in CO₂-equivalent basis) are estimated to double from pre-industrial levels around 2050 for the uncontrolled path (+). The optimal path (□) shows a small reduction in concentrations, whereas emissions stabilization (*) leads to continued increases. Climate stabilization (—) would require declining concentrations.

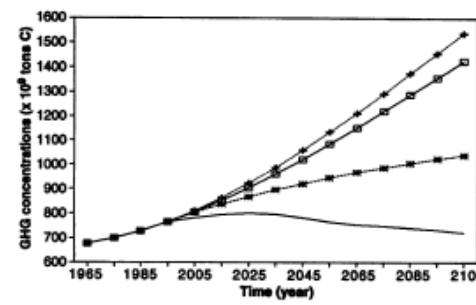


Fig. 3. Projected global mean temperature. According to the DICE model, global mean temperature with no controls (+) is projected to increase 3°C above 1900 levels by 2065. The optimal policy (□) and emissions stabilization (*) would involve only a small reduction in global warming. The maximum feasible policy is climate stabilization (—), which shows significant warming because of the commitment in the current buildup of GHGs.

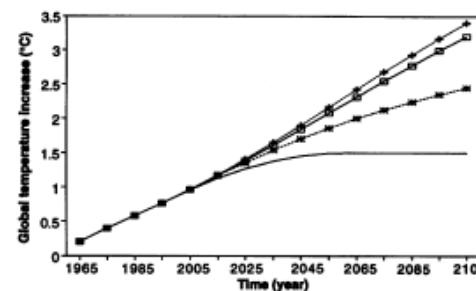
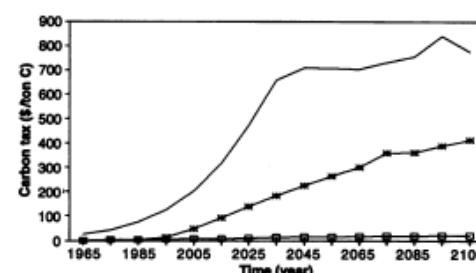


Fig. 4. Carbon taxes in different policies to reduce GHGs. Carbon taxes are a good index of the stringency of policies to slow global warming. A carbon tax would penalize production and consumption of fossil fuels and CFCs and encourage afforestation. Calculations indicate that the optimal carbon tax (□) rises from around \$5 to about \$20 per ton of carbon in 2100. Emissions stabilization (*) and climate stabilization (—) imply sharply rising carbon taxes that would raise coal prices several-fold. Carbon tax given in 1989 U.S. dollars.



The Prize in Economic Sciences

William D. Nordhaus

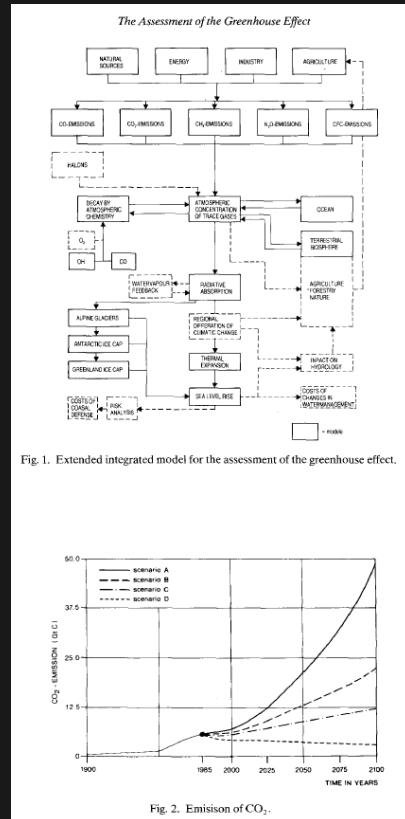
"for integrating climate change into long-run macroeconomic analysis"



© Nobel Media AB. Photo: A. Mahmoud

Nordhaus (1992, Science)
Advanced Environmental Economics

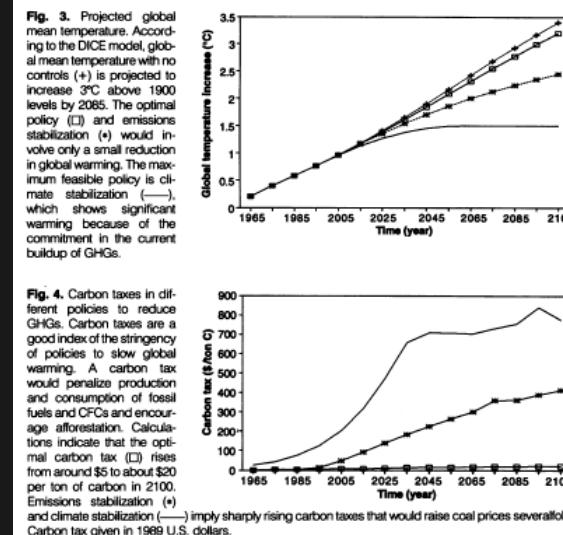
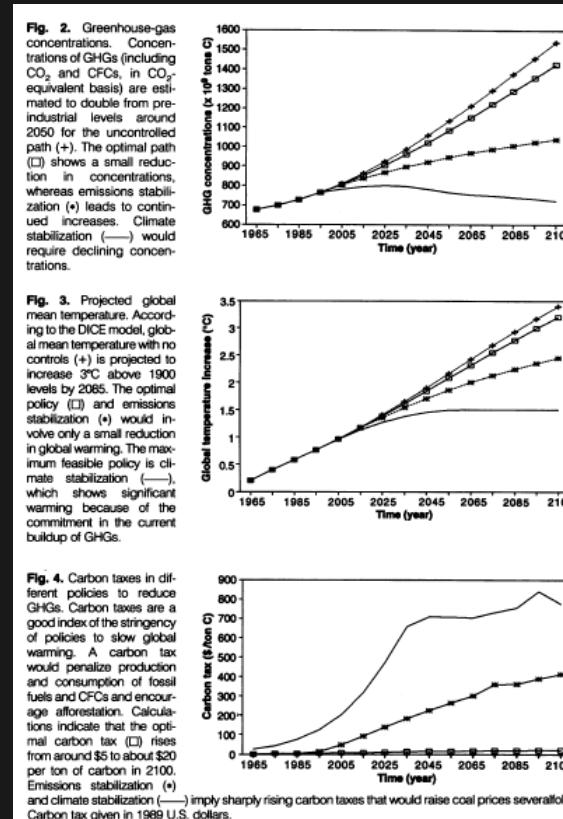
1990s: The emerging landscape of IAMs



- 1990: first assessment report by the IPCC
- 1992: Rio Earth Summit
- establishment UNFCCC
- new climate scenarios used in IPCC reports
- both DP-IAMs and CB-IAMs relevant to global climate policy discourse

Rotmans et al. (1990)

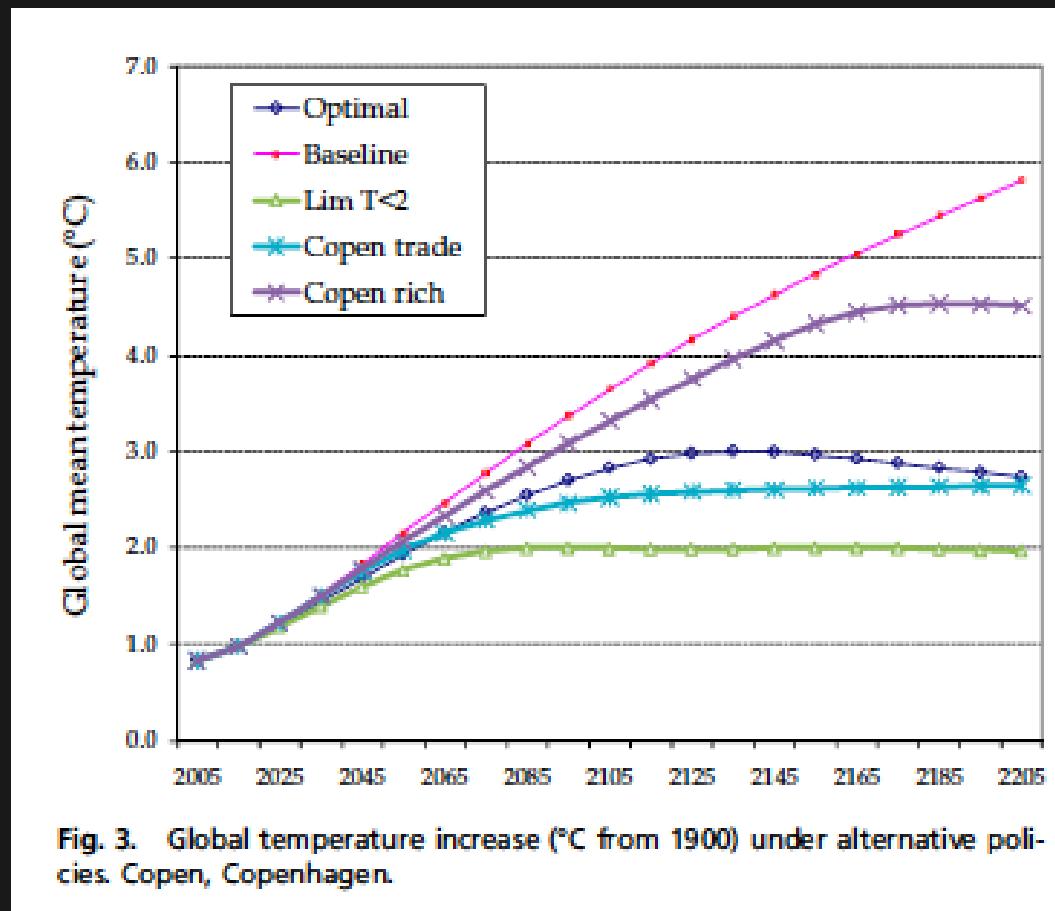
- detailed-process IAMs (DP-IAMs)



Nordhaus (1992)

- cost-benefit IAMs (CB-IAMs)

DICE: from optimal temperature to the SCC



Nordhaus (2010)

Table 1. Global Social Cost of Carbon under Different Assumptions

Scenario	2015	2020	2025	2030	2050
Base parameters:					
Baseline*	18.6	22.1	26.2	30.6	53.1
Optimal controls†	17.7	21.2	25.0	29.3	51.5
2°C limit damage function:					
Maximum†	47.6	60.1	75.5	94.4	216.4
Max of average†	25.0	30.6	37.1	44.7	87.9
Stern Review discounting:					
Uncalibrated*	89.8	103.7	117.4	131.3	190.0
Calibrated*	20.7	25.0	30.1	35.9	66.9
Alternative high discount*	6.4	7.7	9.2	10.9	19.6

Note.—The social cost of carbon is measured in 2005 international US dollars. The years at the top refer to the date at which emissions take place. Therefore, \$18.6 is the cost of emissions in 2015 in terms of consumption in 2015.

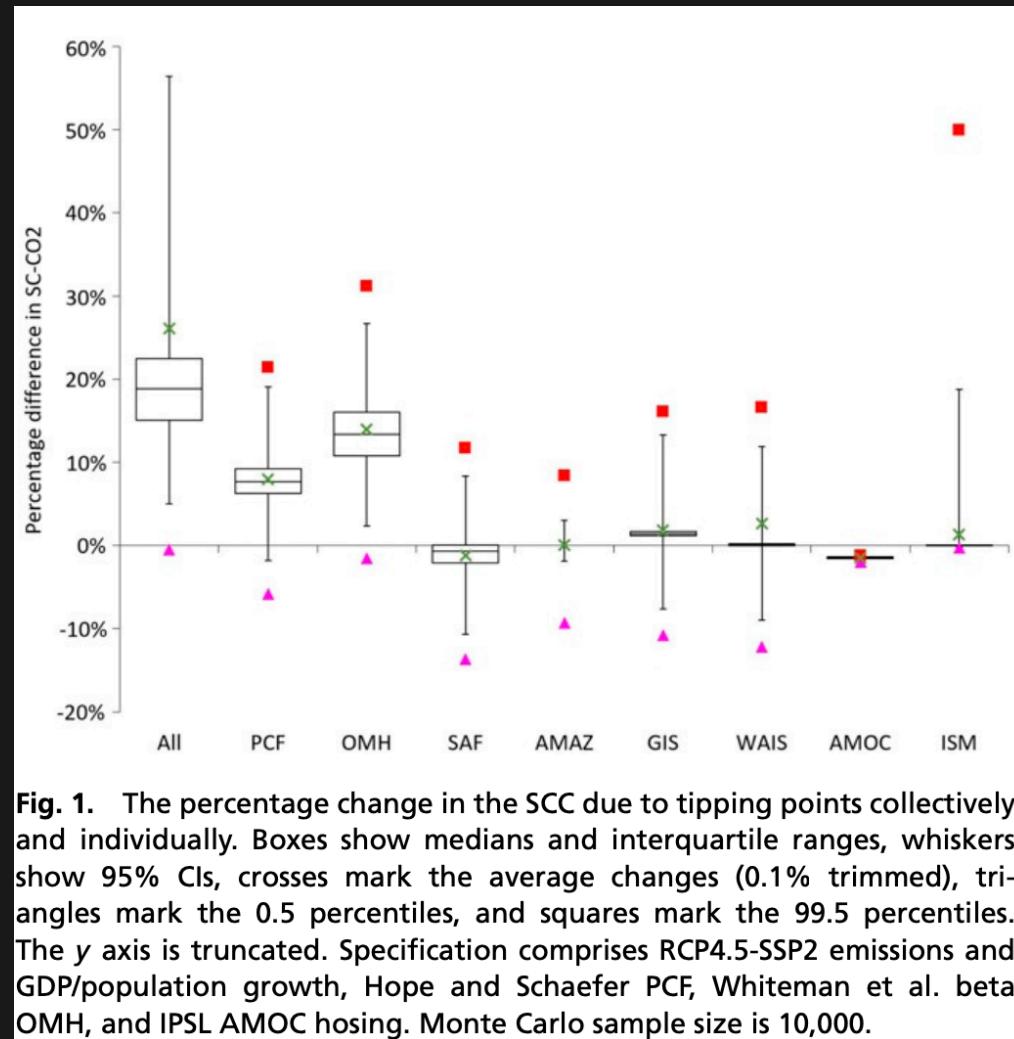
* Calculation along the reference path with current policy.

† Calculation along the optimized emissions path.

Nordhaus (2014)

META: the effect of tipping points on the SCC

- SC-IAM
→ explicitly focused on SCC
- no optimisation
→ assumed baseline path
- How do climate tipping points affect the SCC?



```
1 @defcomp AMOC_emulator begin
2     country = Index()
3
4     # Variables
5     I_AMOC = Variable{Bool}(index=[time])
6     AMOC_decrease = Variable(index=[time], unit="Sv") # AMOC decrease (measured in Sv) starting in t=0
7     deltaT_country_AMOC = Variable(index=[time, country], unit="degC")
8     T_country_AMOC = Variable(index=[time, country], unit="degC")
9     CO2_AMOC = Variable(index=[time], unit="GtCO2")
10    cum_CO2_AMOC = Variable(index=[time], unit="GtCO2")
11
12    # Parameters
13    T_AT = Parameter(index=[time], unit="degC")
14    f_AMOC = Parameter(index=[time])
15
16    beta_AMOC = Parameter() # coefficient representing the sensitivity of AMOC to temperature
17    DecreaseOffset = Parameter() # offset for AMOC decrease by 2010 in Sv (with how much weakening AMOC starts in 2010)
18    eta_AMOC = Parameter() # coefficient representing the sensitivity of the carbon drawdown to AMOC decrease
19    tau_AMOC = Variable(index=[country]) # coefficient representing the sensitivity of the temperature change to AMOC decrease
20    I_tau = Parameter(default=1) # indicator variable for gamma_AMOC
21    gamma_AMOC = Parameter() # coefficient indicating the relative amount of AMOC slowdown in given calculation
22
23    # delta_AMOC = Parameter(index=[time, country], default=3)
24    max_deltaT_country_AMOC = Parameter(index=[country], unit="degC")
25
26    T_country_base = Parameter(index=[time, country], unit="degC")
27    T_AT_2010 = Parameter(default=-0.0354, unit="degC")
28    AMOC_2010 = Parameter(default=18.0, unit="Sv")
```

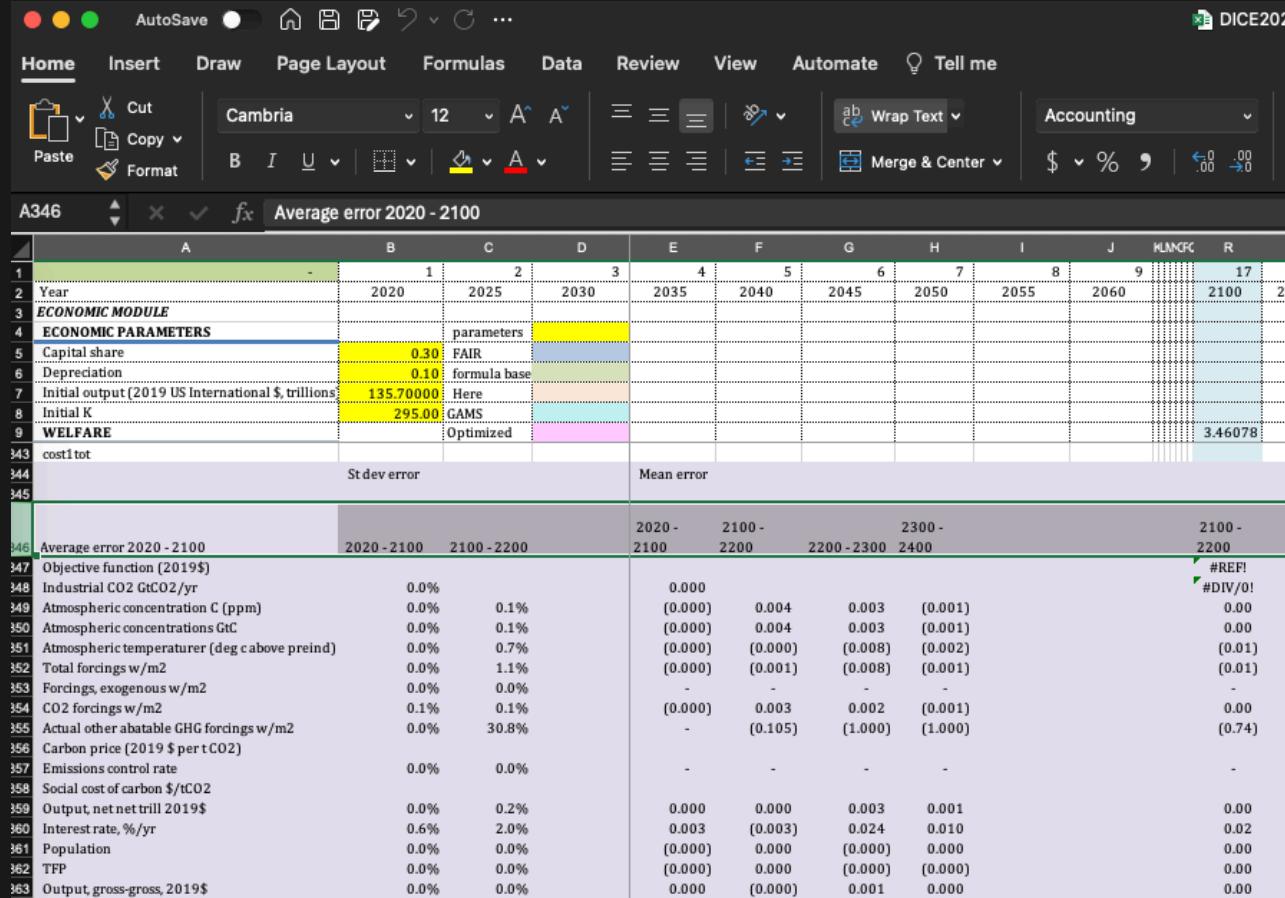
2. How to code IAMs?

Generally, one uses programming tools. The most common

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Generally, one uses programming tools. The most common one.

...you might laugh...

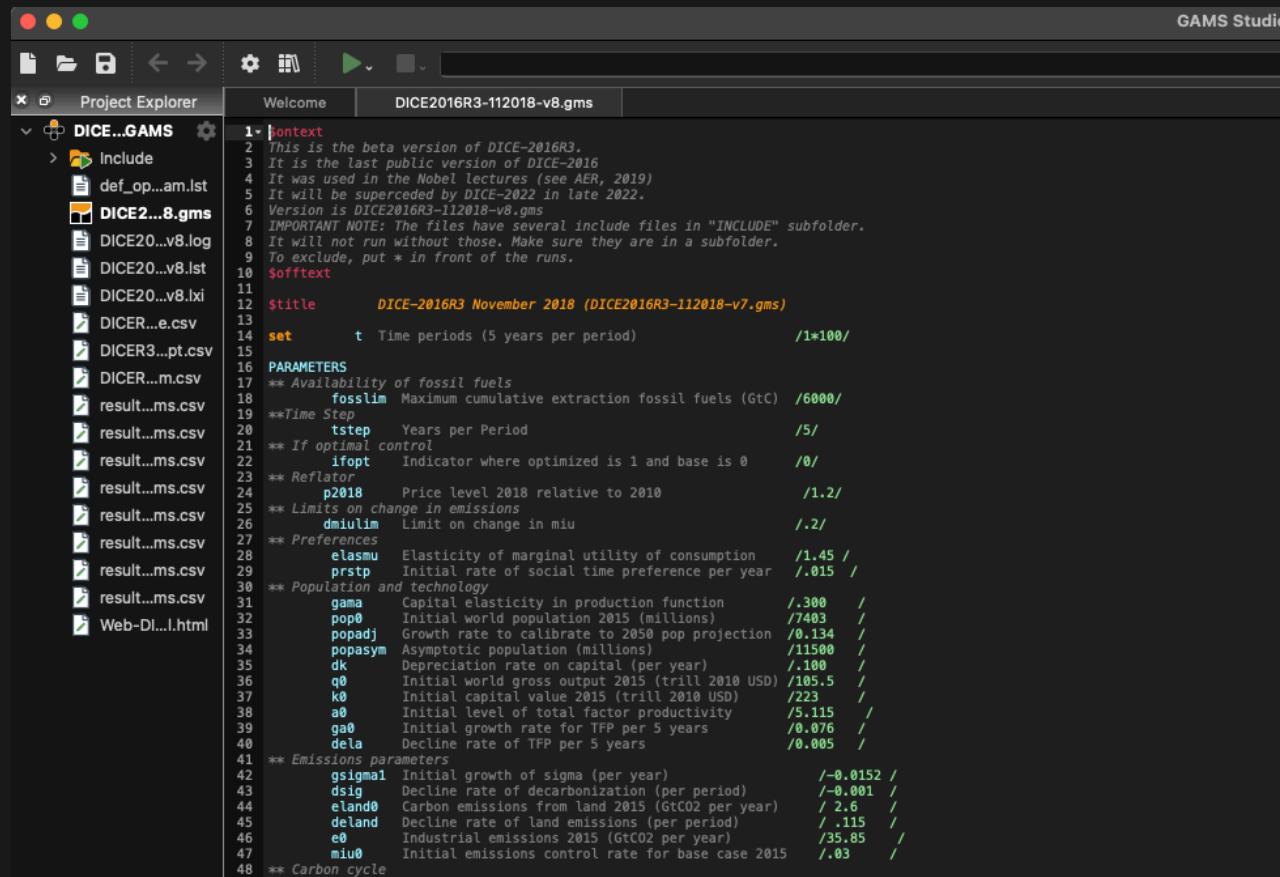


A screenshot of a Microsoft Excel spreadsheet titled "DICE2023". The spreadsheet contains several sections of data:

- Year:** 2020, 2025, 2030, 2035, 2040, 2045, 2050, 2055, 2060, 2100, 2100, 2100.
- ECONOMIC MODULE**
- ECONOMIC PARAMETERS:**
 - Capital share: 0.30
 - Depreciation: 0.10
 - Initial output (2019 US International \$, trillions): 135.70000
 - Initial K: 295.00
- WELFARE:** costitot, St dev error, Mean error.
- Objective function (2019\$):** Industrial CO2 GtCO2/yr, Atmospheric concentration C (ppm), Atmospheric concentrations GtC, Atmospheric temperaturer (deg c above preind), Total forcings w/m2, Forcings, exogenous w/m2, CO2 forcings w/m2, Actual other abatable GHG forcings w/m2, Carbon price (2019 \$ per tCO2), Emissions control rate, Social cost of carbon \$/tCO2, Output, net trill 2019\$, Interest rate, %/yr, Population, TFP, Output, gross-gross, 2019\$.



Also common: GAMS



The screenshot shows the GAMS Studio interface. The left pane is the Project Explorer, which lists various files including 'DICE...GAMS', 'Include', 'DICE2...8.gms', 'DICE20...v8.log', 'DICE20...v8.lst', 'DICE20...v8.lxi', 'DICER...e.csv', 'DICER3...pt.csv', 'DICER...m.csv', 'result...ms.csv', 'result...ms.csv', 'result...ms.csv', 'result...ms.csv', 'result...ms.csv', 'result...ms.csv', 'result...ms.csv', 'Web-DI...l.html'. The right pane is the code editor with the file 'DICE2016R3-112018-v8.gms' open. The code is a GAMS script for the DICE model, defining parameters like fossilim, tstep, ifopt, p2018, and various elasticities and growth rates.

```

1 *!context
2 This is the beta version of DICE-2016R3.
3 It is the last public version of DICE-2016
4 It was used in the Nobel lectures (see AER, 2019)
5 It will be superceded by DICE-2022 in late 2022.
6 Version is DICE2016R3-112018-v8.gms
7 IMPORTANT NOTE: The files have several include files in "INCLUDE" subfolder.
8 It will not run without those. Make sure they are in a subfolder.
9 To exclude, put * in front of the runs.
10 $offtext
11 $title      DICE-2016R3 November 2018 (DICE2016R3-112018-v7.gms)
12 $set      t  Time periods (5 years per period)           /1*100/
13
14 *PARAMETERS
15 ** Availability of fossil fuels
16     fossilim Maximum cumulative extraction fossil fuels (GtC) /6000/
17 **Time Step
18     tstep    Years per Period                         /5/
19 ** If optimal control
20     ifopt    Indicator where optimized is 1 and base is 0   /0/
21 ** Reflator
22     p2018   Price level 2018 relative to 2010          /1.2/
23 ** Limits on change in emissions
24     dmilim  Limit on change in miu                      /.2/
25 ** Preferences
26     elasmu  Elasticity of marginal utility of consumption /1.45 /
27     prstp   Initial rate of social time preference per year/.015 /
28
29 ** Population and technology
30     gama    Capital elasticity in production function   /.300  /
31     pop0    Initial world population 2015 (millions)       /7403  /
32     popadj  Growth rate to calibrate to 2050 pop projection /0.134 /
33     popasym Asymptotic population (millions)             /11500 /
34     dk      Depreciation rate on capital (per year)       /.100  /
35     q0      Initial world gross output 2015 (trill 2010 USD) /105.5 /
36     k0      Initial capital value 2015 (trill 2010 USD)   /223  /
37     a0      Initial level of total factor productivity   /5.115 /
38     ga0    Initial growth rate for TFP per 5 years       /0.076 /
39     dela   Decline rate of TFP per 5 years                 /0.005 /
40
41 ** Emissions parameters
42     osignal Initial growth of sigma (per year)           /-0.0152 /
43     dsig    Decline rate of decarbonization (per period)  /-0.001 /
44     eland0  Carbon emissions from land 2015 (GtCO2 per year) / 2.6 /
45     deland  Decline rate of land emissions (per period)   /.115  /
46     e0      Industrial emissions 2015 (GtCO2 per year)    /35.85 /
47     miu0   Initial emissions control rate for base case 2015 / .03  /
48
49 ** Carbon cycle

```

- nonlinear optimisation
- fast and reliable solvers
- proprietary software
- restrictive UI and ecosystem



The open alternative: Mimi

[README](#) [License](#)

[Run CI on main](#) passing [Run model tests](#) passing [codecov](#) 85% [docs](#) stable

Mimi - Integrated Assessment Modeling Framework

Mimi is a [Julia](#) package that provides a component model for [integrated assessment models](#), as described in detail on the [Mimi Framework Homepage](#). The [Documentation](#) includes information on the installation and use of this package, step-by-step tutorials, how-to guides, and technical reference. The development team closely monitors the [Mimi Framework forum](#) and we suggest this as a starting place for any questions users may have.

Also, note that if at any point julia-related issues with workflows, environments, and/or package versioning become frustrating, please do not hesitate to reach out via the [forum](#). This can be a hurdle to learn at first, but taking a moment to get it right early will save you a lot of time down the road. We are more than happy to help you, and are getting together some standardized resources in the meantime.

- package within Julia
- entirely open-source
- many IAMs and impact models available
- in principle modular and interoperable
- used by the EPA for US SCC calculations



For the Mimi documentation click [here](#).

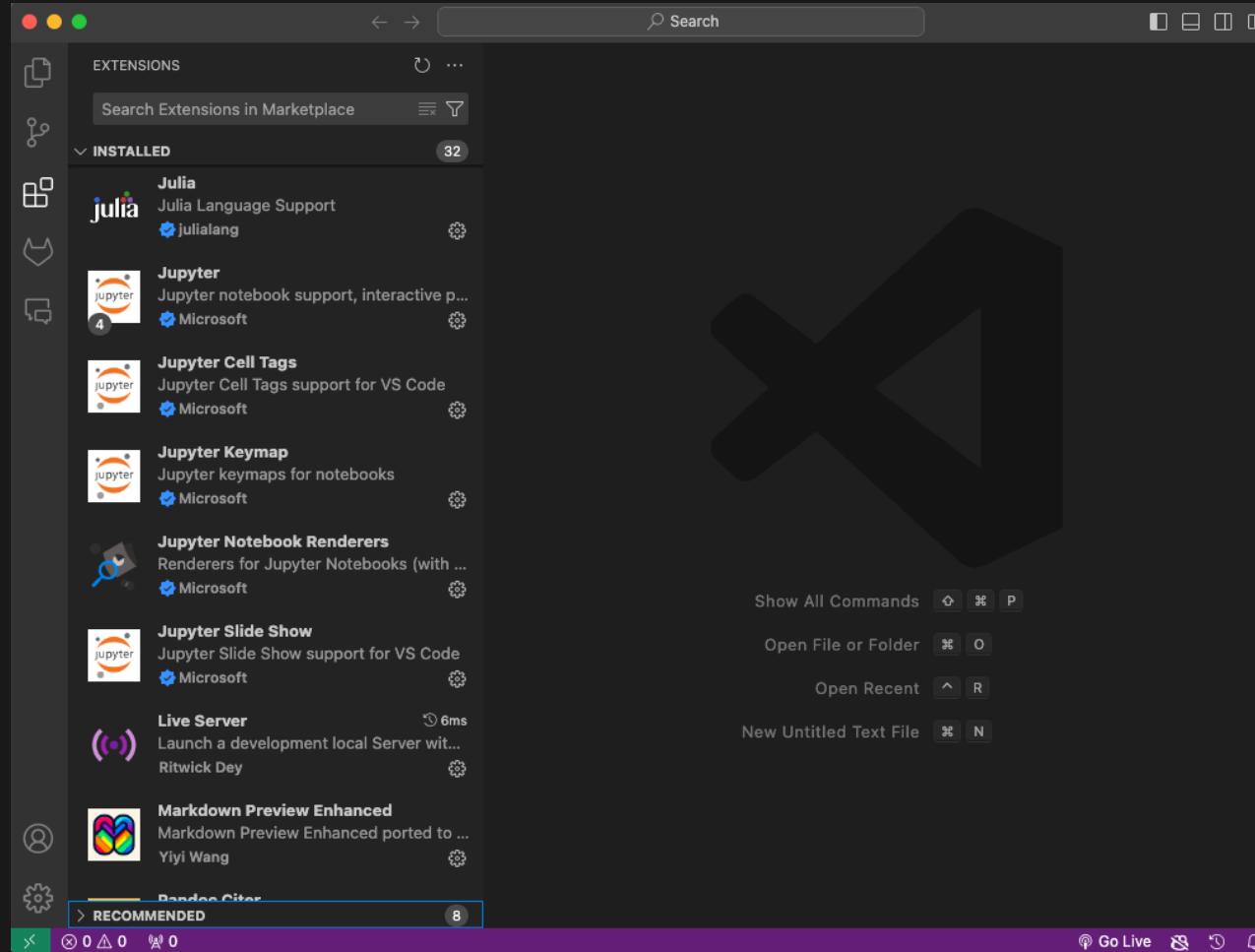


Break (& time for questions)

```
1 @defcomp AMOC_emulator begin
2     country = Index()
3
4     # Variables
5     I_AMOC = Variable{Bool}(index=[time])
6     AMOC_decrease = Variable(index=[time], unit="Sv") # AMOC decrease (measured in Sv) starting in t=0
7     deltaT_country_AMOC = Variable(index=[time, country], unit="degC")
8     T_country_AMOC = Variable(index=[time, country], unit="degC")
9     CO2_AMOC = Variable(index=[time], unit="GtCO2")
10    cum_CO2_AMOC = Variable(index=[time], unit="GtCO2")
11
12    # Parameters
13    T_AT = Parameter(index=[time], unit="degC")
14    f_AMOC = Parameter(index=[time])
15
16    beta_AMOC = Parameter() # coefficient representing the sensitivity of AMOC to temperature
17    DecreaseOffset = Parameter() # offset for AMOC decrease by 2010 in Sv (with how much weakening AMOC starts in 2010)
18    eta_AMOC = Parameter() # coefficient representing the sensitivity of the carbon drawdown to AMOC decrease
19    tau_AMOC = Variable(index=[country]) # coefficient representing the sensitivity of the temperature change to AMOC decrease
20    I_tau = Parameter(default=1) # indicator variable for gamma_AMOC
21    q_AMOC = Parameter() # coefficient indicating the relative amount of AMOC slowdown in a given calibration [%]
22
23    # Data
24    max_deltaT_country_AMOC = Parameter(index=[country], unit="degC")
25    T_country_base = Parameter(index=[time, country], unit="degC")
26
27
28    T_AT_2010 = Parameter(default=0.854, unit="degC")
29    AMOC_2010 = Parameter(default=18.0, unit="Sv")
30
31    function run_timestep(pp, vv, dd, tt)
32
33        # AMOC decrease (measured in Sv) starting in t=0 and assumed to be linear
34        # this variable could also be directly calibrated to ESM output
35        vv.AMOC_decrease[tt] = pp.DecreaseOffset + pp.beta_AMOC * (pp.T_AT[tt] - pp.T_AT_2010)
36        vv.I_AMOC[tt] = 0
37
38        if is_first(tt)
39
40            # calculate CO2 release depending on AMOC strength
41            # while not imposing a maximum CO2 release
42            vv.CO2_AMOC[tt] = pp.eta_AMOC * vv.AMOC_decrease[tt]
43            vv.cum_CO2_AMOC[tt] = vv.CO2_AMOC[tt]
44
45            for cc in dd.country
46                vv.tau_AMOC[cc] = pp.I_tau * pp.max_deltaT_country_AMOC[cc] ./ (pp.q_AMOC * pp.AMOC_2010)
47            end
48        else
49            # calculate CO2 release depending on AMOC strength
```

3. How to run an IAM with Mimi

Prerequisite 1: a functioning coding environment



Do you all have this?
Can you open the lecture folder?
Can you update it?

Prerequisite 2: Julia and Jupyter installations

```

my_message_to_the_world = "Hello world, how are you doing today?"
println(my_message_to_the_world) # println prints the message to the console and starts a new line

```

If everything worked correctly, it should look like this:

```

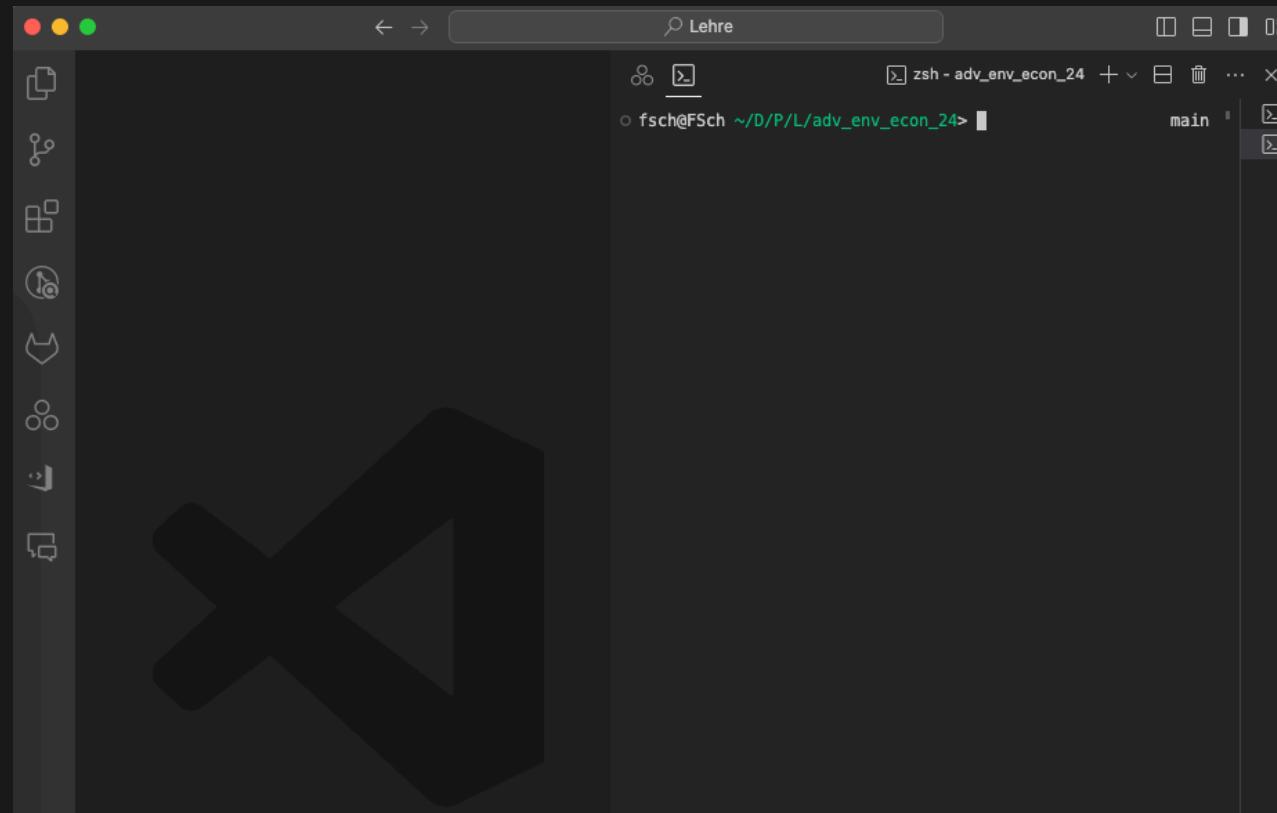
my_message_to_the_world = "Hello world, how are you doing today?"
println(my_message_to_the_world) # println prints the message to the console and starts a new line

```

Can you open and render the
Intro_Notebook.ipynb?
Does the Julia cell run?

Prerequisite 3: a proper Julia environment

Julia environment: a sandbox with a set of packages



1. Open the terminal within VS Code
2. Type **julia** and then type **]**
3. Installed packages: **status**
4. New environment in current folder: **activate .**

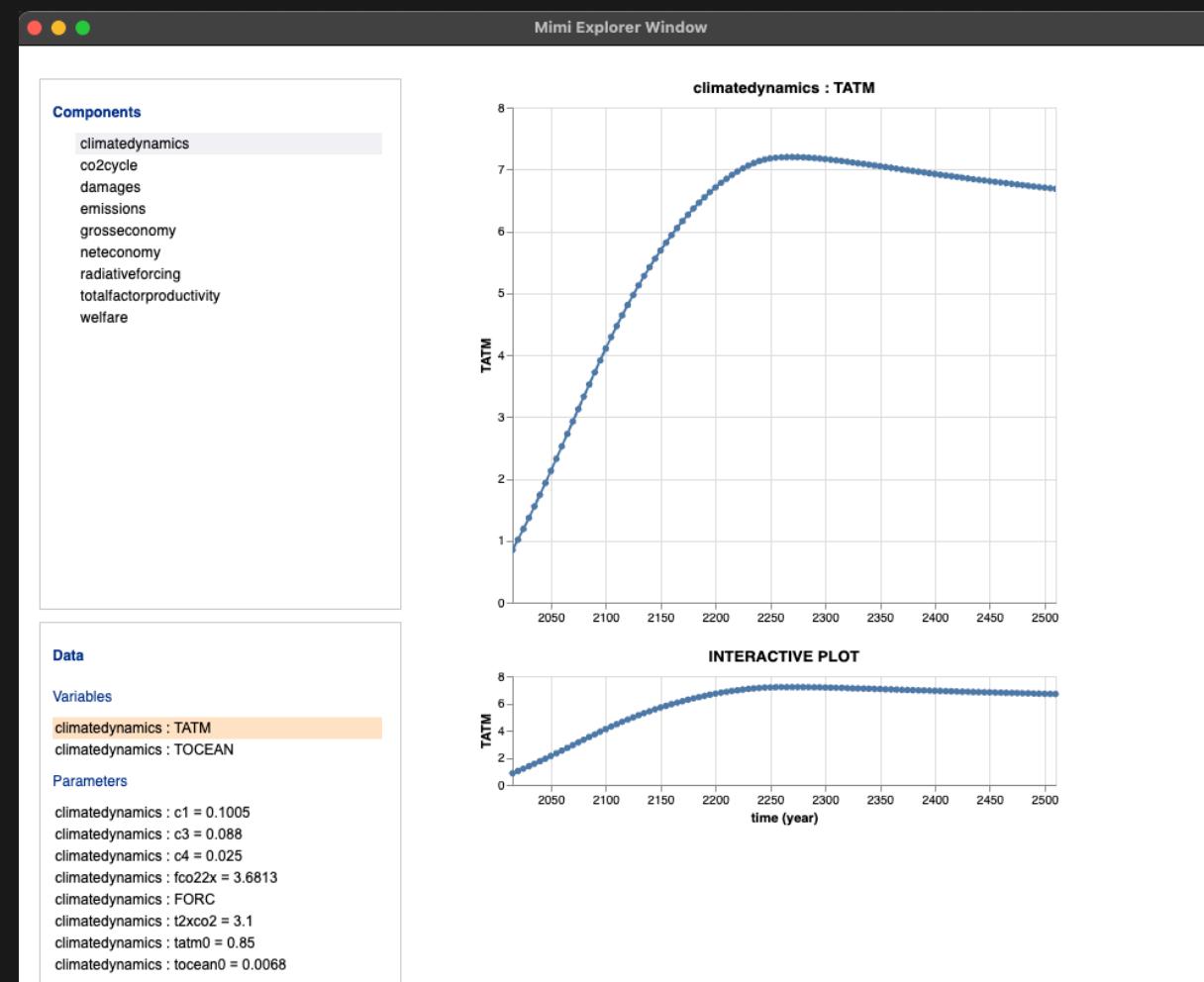
Running MimiDICE2016R2

```

1 # import packages
2 using Mimi
3 using MimiDICE2016R2
4
5 # get model and build it
6 m = MimiDICE2016R2.get_model()
7 run(m)
8
9 # explore in graphical user interface
10 explore(m)

```

- MimiDICE2016R2 does not optimise
- hence: only simulation based on given parameter values
- for optimisation see here



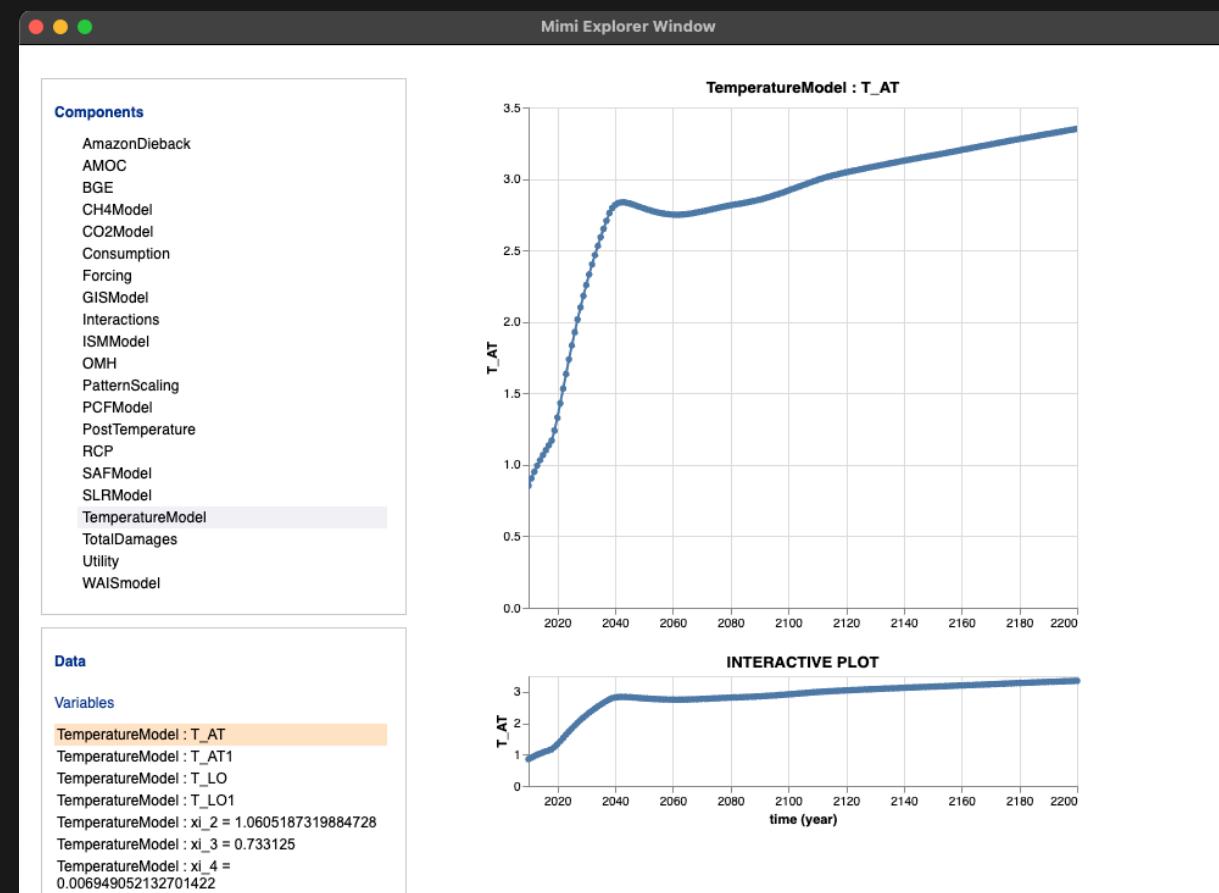
Running META-2021

```

1 # import packages by calling main Julia file
2 include("./META-2021/src/MimiMETA.jl")
3
4 # get model and build it
5 model = full_model(rcp="RCP4.5", ssp="SSP2")
6 run(model)
7
8 # explore in graphical user interface
9 explore(model)

```

- META not a package
- hence: clone and import file
- challenge: relative file paths



Next steps

- change parameters of a model
- change equations of a model
- check output and make some plots
- optimise a model